

## **A. PROJECT INFORMATION**

**Report type:**

Final Report

**Time Period:**

April 1, 2012 – September 15, 2015

**Project title:**

Assessment of Plant Fertility and Fertilizer Requirements for Agricultural Crops in California

**FREP Grant Number:**

11-0485-SA

**Project leaders:**

William R. Horwath  
Professor of Soil Biogeochemistry  
1111 Plant and Environmental Sciences Building  
Department of Land, Air and Water Resources  
University of California  
Davis, CA, 95616  
(530) 754-6029  
wrhorwath@ucdavis.edu

Daniel Geisseler  
Assistant Cooperative Extension Specialist  
1111 Plant and Environmental Sciences Building  
Department of Land, Air and Water Resources  
University of California  
Davis, CA, 95616  
(530) 754-9637  
djgeisseler@ucdavis.edu

## **B. OBJECTIVES**

The overall objectives of the project are (i) to make technical research data from FREP-funded projects readily available to growers and crop advisers through a user-friendly, web-based database, and (ii) to write crop-specific fertilization guidelines for major crops grown in California by synthesizing results from FREP-funded research and the scientific literature.

## **C. ABSTRACT**

More than 170 projects have been funded by the California Department of Food and Agriculture Fertilizer Research and Education Program (CDFA FREP) since the early 1990s. In collaboration with CDFA-IT, a database has been created and key information from the more than 150 final reports, which are currently available, has been entered into the database. The database is accessible online (<http://www.cdfa.ca.gov/is/frep/Default.aspx>). The website allows searching the database for specific projects by entering keywords or using different search criteria, namely crop, county or date range.

In order to present the wealth of information in an even more user-friendly way, crop-specific fertilization guidelines have been written. The guidelines are based on results of FREP-funded projects and data from the scientific literature. A webpage has been designed where the completed guidelines are presented in a user-friendly, interactive way (<http://apps.cdfa.ca.gov/frep/docs/guidelines.html>). Guidelines of 17 major crops grown in California, both specialty and non-specialty crops, are now available online.

## **D. INTRODUCTION**

California growers are facing increasing pressure to improve nitrogen use efficiency in crop production as stricter regulatory and reporting requirements are being implemented.

This project aims to make findings of projects funded by FREP since the early 1990s available to growers and crop advisers by creating a user-friendly, web-based database. In addition, results from FREP-funded projects as well as data from the scientific literature shall be summarized and web-based fertilization guidelines for major crops grown in California shall be created.

The present project is a collaborative effort between the Department of Land, Air and Water Resources (LAWR) at the University of California, Davis and the California Department of Food and Agriculture Fertilizer Research and Education Program (CDFA FREP). Initially, the project was funded for one year to create the database. Two additional years of funding were received to develop crop fertilization guidelines for major crops grown in California. The work description of this report includes the tasks of the entire project.

## **E. WORK DESCRIPTION**

The following tasks were part of the project:

1. Synthesize FREP final reports.

2. Assisting CDFA IT and FREP in the development of a searchable online database.
3. Enter key information of each final report into the database.
4. Write nitrogen, phosphorus and potassium fertilization guidelines for major crops grown in California.
5. Write discussions focusing on specific topics of nutrient cycling and site-specific nutrient management to complement the guidelines.
6. Write final report with major conclusions and future directions for research on fertilizer use and management.

### **Tasks 1 to 3:**

Tasks 1 to 3 have been done concurrently. While reading the reports, key information was entered into a database, including a summary of the results and links to sites with closely related content.

Approximately 150 final reports are currently available. They have been summarized and the data entered into the database (Figures 1 and 2). The database has been online since summer 2012 at:

<http://www.cdfa.ca.gov/is/frep/Default.aspx>

To simplify addition of project summaries to the database, a factsheet, which is now integrated into the final report, was created in collaboration with FREP. The data reported by the authors on the factsheet can be directly entered into the database.

Final reports submitted after this project is completed will be summarized and added to the database in a follow-up project. Information on ongoing projects will also be added to the database in the future.

### **Task 4:**

Nitrogen, phosphorus and potassium fertilization guidelines have been written for 17 crops and are available online (Figures 3 and 4). They can be accessed here:

<http://apps.cdfa.ca.gov/frep/docs/guidelines.html>

The site went online in summer 2013. The list of crops includes alfalfa, almonds, barley, broccoli, cauliflower, citrus, corn, cotton, grapes, lettuce, pistachio, prunes and plums, rice, strawberries, processing tomatoes, wheat, and walnuts. In addition, guidelines for peaches and nectarines have been written and are under review. They will be added shortly. Information on selected micronutrients is included for crops where deficiencies are common. Where information is available, the effects of irrigation system and cover crops are also discussed in the crop-specific guidelines.

### **Task 5:**

The information now available on the website goes far beyond crop-specific guidelines. The following contents have been added to the site:

- Documents with additional information have been added in the form of pdf files. The topics include historic overviews of the production and fertilization of each crop, soil and tissue

sampling instructions for field crops and vegetables, soil sampling instructions for orchards, economically optimal nitrogen rate in cotton production, potassium fixation in San Joaquin Valley soils, and nitrogen dynamics in soil.

- A list of online resources for nutrient and irrigation management has been added (<http://apps.cdfa.ca.gov/frep/docs/resources.html>). Currently, the list contains more than 30 links to relevant sites.
- Based on requests by growers and CCAs, a series of webpages were added, presenting data on nitrogen uptake during the growing season, nitrogen partitioning in the plant and nitrogen removed with the harvested plant parts ([http://apps.cdfa.ca.gov/frep/docs/N\\_Uptake.html](http://apps.cdfa.ca.gov/frep/docs/N_Uptake.html)). Most of the data included is from studies carried out in California. The webpages are linked with the guidelines and are a valuable resource for the preparation of nitrogen budgets.
- The guidelines for almonds, strawberries and processing tomatoes have been translated to Spanish.
- For an optimal fertilization program, growers need to make field-specific adjustments, which depend on expected yield, soil properties, local weather conditions and crop management. These factors affect crop nitrogen uptake, non-fertilizer nitrogen inputs and potential nitrogen losses. The major factors affecting soil nitrogen availability have been summarized on the page "Discussion about site-specific adjustments and losses" (<http://apps.cdfa.ca.gov/frep/docs/Adjustments.html>).

#### **Task 6:**

This final report was submitted to FREP in October 2015. An analysis of research gaps and future directions for research is attached to this report (Appendix 1).

## **F. RESULTS**

### **FREP Database**

In collaboration with CDFA-IT, a website has been created which allows searching for specific projects in a database of FREP funded projects. The website provides an overview for each project. The site went online in summer 2012 and can be accessed at

<http://www.cdfa.ca.gov/is/frep/Default.aspx>

On the website, users can search for specific topics by either entering a keyword or choosing a crop type, a county, or a date range from a drop-down menu (Figure 1). From the list of projects that meet the search criteria, users can access summaries of specific projects (Figure 2). In addition to the summary, each page also provides links to the final report, to contributions to the FREP proceedings, and to external sites closely related to the project, such as articles written by the project leaders that are available online. Additional projects are added to the database when the final reports are submitted to FREP.

## **Fertilization guidelines**

Since the beginning of the FREP program, a large number of research projects have been completed to address different aspects of fertilizer management of crops grown in California. For many crops, however, a comprehensive overview of the current, research based knowledge of fertilizer management is missing. The fertilization guidelines aim to close this gap by providing a summary of relevant studies with a focus on projects carried out in California. As part of this project, a user-friendly and visually interactive web site was created (Figure 3).

The guidelines present accurate and timely information about application rates, timing of application, fertilizer placement and types of fertilizers (the 4R concept; Figure 4). In addition, deficiency symptoms are described, the use of soil and plant tissue analyses is discussed and instructions for representative sampling are provided. Currently, the guidelines provide information about nitrogen, phosphorus, and potassium fertilization. Information on selected micronutrients is included for crops where deficiencies are common. The design of the web page allows adding other nutrients if desired. Guidelines for 17 crops are now available online at

<http://apps.cdfa.ca.gov/frep/docs/guidelines.html>

The guidelines are a general overview of fertilization practices based on research and shall provide a basis for in-depth discussions with local farm advisors or fertilization experts about site-specific adjustments. The information now available on the website goes far beyond crop specific guidelines (see task 5 for more details on additional content).

## **G. DISCUSSION AND CONCLUSIONS**

By making the database available to the public, the major objective of the first phase of the project has been met for the more than 150 projects for which final reports are available. Fertilization guidelines for 17 major crops have been written and are also available online on a user-friendly, interactive page (objective 2).

The database and the guidelines together facilitate and improve access to nutrient management related information considerably. The websites present a comprehensive source of information for growers, certified crop advisers and other interested stakeholders.

## **H. PROJECT IMPACTS**

The products of this project are freely available online to reach a maximum number of growers and crop advisers. The information presented advances the environmentally safe and agronomically sound use of fertilizing materials.

The sites generate several hundred unique page views each month. This number is likely to increase as additional data is added and as growers are increasingly in need of nutrient management related information due to stricter reporting requirements. In addition to growers and crop advisers, the guidelines are also used by NRCS staff and serve as a source of information in nutrient management and agronomy classes.

## I. OUTREACH ACTIVITIES

The entire project is an outreach activity for FREP. Specific outreach activities include:

- Presentation at the Annual FREP Conference on October 30-31, 2012 in Modesto: Horwath, W.R., Geisseler, D. Assessment of Plant Fertility and Fertilizer Requirements for Agricultural Crops in California ([www.cdafa.ca.gov/is/ffldrs/frep/pdfs/2012\\_Proceedings\\_FREP.pdf](http://www.cdafa.ca.gov/is/ffldrs/frep/pdfs/2012_Proceedings_FREP.pdf))
- Presentation at the EPA workshop 'Reactive Nitrogen Research for San Joaquin Valley' on June 4-5, 2013 in Fresno: Geisseler, D., Horwath, W.R. Nutrient Management Guidelines for Major Crops in California (<http://www.epa.gov/region9/ag/workshop/nitrogen/index.html>)
- Presentation at the meeting of the steering committee for the CCA training in Davis on June 7, 2013: Geisseler, D., Horwath, W.R. Nutrient Management Guidelines for Major Crops in California.
- Presentation at the Annual FREP Conference on October 29-30, 2013 in Modesto: Geisseler, D., Horwath, W.R. Assessment of Plant Fertility and Fertilizer Requirements for Agricultural Crops in California ([www.cdafa.ca.gov/is/ffldrs/frep/pdfs/2013\\_Proceedings\\_FREP.pdf](http://www.cdafa.ca.gov/is/ffldrs/frep/pdfs/2013_Proceedings_FREP.pdf)).
- Presentation at the California Plant and Soil Conference on February 04-05, 2014 in Fresno: Geisseler, D., Horwath, W.R. Nutrient Management Guidelines for Major Crops in California.
- Presentation at the Nitrogen Management Training Program for California Certified Crop Advisers on January 14-15, 2014 in Modesto. Geisseler, D., Maan, A. Nutrient Management Resources.
- Presentation at the Nitrogen Management Training Program for California Certified Crop Advisers on February 18-19, 2014 in Woodland. Geisseler, D., Maan, A. Nutrient Management Resources.
- Presentation at the Nitrogen Management Training Program for California Certified Crop Advisers on February 25-26, 2014 in Fresno. Geisseler, D., Maan, A. Nutrient Management Resources.
- Presentation at the Nitrogen Management Training Program for California Certified Crop Advisers on March 5-6, 2014 in Salinas. Geisseler, D., Maan, A. Nutrient Management Resources.
- Presentation at the Nitrogen Management Training Program for California Certified Crop Advisers on March 11-12, 2014 in Tulare. Geisseler, D., Maan, A. Nutrient Management Resources.
- Geisseler, D., Horwath, W.R. Fertilization guidelines for major crops in California. Poster presented at the UC Davis Russell Ranch Sustainable Agriculture Field Day 2014 on May 28, 2014, Davis, CA.
- Geisseler, D., 2014. Online tools to improve access to research-based nutrient management information. Oral presentation at the Meeting of the Association of American Plant Food Control Officials on July 29, 2014, Sacramento, CA.

- Geisseler, D. 2014. Optimizing N application rates while minimizing the risk of yield losses. Oral presentation at the California Department of Food and Agriculture - Fertilizer Research & Education Program Conference, October 29-30, 2014, Modesto, CA.
- Geisseler, D., Horwath, W.R., 2014. Assessment of plant fertility and fertilizer requirements for agricultural crops in California. Project summary written for the Proceedings of the California Department of Food and Agriculture - Fertilizer Research & Education Program Conference, October 29-30, 2014, Modesto, CA.
- Geisseler, D. Introducing myself and the guidelines at the 2014 Vegetable Crops Program Team Meeting on December 09, 2014, Davis, CA.
- Geisseler, D., Moradi, B., Horwath, W.R. Fertilization guidelines for major crops in California. Poster presented at the California Almond Conference on December 9-10, 2014, Sacramento, CA.
- Moradi, B.A., Geisseler, D., Nutrient management tools and resources. Nitrogen Management Training Program for California Certified Crop Advisers, January 13, 2015. Fresno, CA.
- Geisseler D., General guidelines vs. site-specific nutrient management. California Plant and Soil Conference. February 4, 2015, Fresno, CA.
- Geisseler, D. Introducing myself and the fertilization guidelines at the 2015 Annual Water Program Team Meeting on February 12, 2015, Davis, CA.
- Geisseler, D. Optimizing nutrient management – Tools and approaches. 2015 Irrigation and Nutrient Management Meeting, February 19, 2015. Salinas, CA
- Moradi, B.A., Geisseler, D., Nutrient management tools and resources. Nitrogen Management Training Program for California Certified Crop Advisers, February 24, 2015. San Luis Obispo, CA.
- Moradi, B.A., Geisseler, D., Nutrient management tools and resources. Nitrogen Management Training Program for California Certified Crop Advisers, March 10, 2015. Sacramento, CA.
- Geisseler, D. Introducing myself and the fertilization guidelines at the 2015 Annual Pomology Program Team Meeting on March 23, 2015, Davis, CA.
- Moradi, B.A., Geisseler, D., Horwath, W.R., Fertilizer Research and Education Program (FREP): Fertilization guidelines and other online resources. Kern River Watershed Coalition Authority, April 24, 2015, Merced, CA.
- Geisseler, D. Optimizing Nutrient Management – Tools and Approaches. Russell Ranch Field Day, May, 21, 2015. University of California, Davis, CA.
- Planting seeds blog on July 2<sup>nd</sup>, 2012: Got Data? CDFA Unveils New Searchable Database of FREP Fertilizer Research Projects (<http://plantingseedsblog.cdfa.ca.gov/wordpress/?p=2023>).

- Planting seeds blog on August 1<sup>st</sup>, 2013: CDFA's Fertilizer Research and Education Program (FREP) Unveils New Crop Fertilization Guidelines (<http://plantingseedsblog.cdfa.ca.gov/wordpress/?p=4457>).
- Article in AgAlert on August 14, 2013: CDFA Posts Fertilizing Guidelines (<http://www.agalert.com/story/default.aspx?id=5837>)
- UC Davis College of Agricultural and Environmental Sciences News Beat on August 20, 2013: CDFA Posts Fertilizing Guidelines (<http://ucdaviscaes.wordpress.com/2013/08/20/cdfa-posts-fertilizing-guidelines/>)



## **J. FACTSHEET**

### **1. Project Title:**

Assessment of Plant Fertility and Fertilizer Requirements for Agricultural Crops in California

### **2. Grant Agreement Number:**

11-0485-SA

### **3. Project Leaders:**

Horwath, W.R., Geisseler, D., Department of Land, Air and Water Resources, University of California, Davis

### **4. Start Year/End Year:**

2012-2015

### **5. Location:**

Statewide

### **6. County:**

Statewide

### **7. Highlights:**

- An online searchable database of completed FREP projects was created.
- The available literature on nutrient management of 17 major crops grown in California was summarized.
- The summaries were used to create user-friendly online fertilization guidelines.

### **8. Introduction:**

California growers are facing increasing pressure to improve nitrogen use efficiency in crop production as stricter regulatory and reporting requirements are being implemented.

This project aims to make findings of projects funded by FREP since the early 1990s available to growers and crop advisors by creating a searchable, web-based database. In addition, results from FREP-funded projects as well as data from the scientific literature shall be summarized and web-based fertilization guidelines for major crops grown in California shall be created.

### **9. Methods/Management:**

In collaboration with CDFA-IT, an online database of completed FREP projects has been created. On the website, users can search for specific topics by either entering a keyword or

choosing a crop type, a county, or a date range from a drop-down menu. From the list of projects that meet the search criteria, users can access summaries of specific projects. In addition to the summary, each page also provides links to the final report, to contributions to the FREP proceedings, and to external sites closely related to the project, such as articles written by the project leaders that are available online. The database can be accessed at

<http://www.cdfa.ca.gov/is/frep/Default.aspx>

In order to present the wealth of information from reports, the scientific literature and University of California Cooperative Extension newsletters in a highly user-friendly way, crop-specific fertilization guidelines have been written. Guidelines of 17 major crops grown in California are available on this website:

<http://apps.cdfa.ca.gov/frep/docs/guidelines.html>

The guidelines present accurate and timely information about application rates, timing of application, fertilizer placement and types of fertilizers (the 4Rs). In addition, deficiency symptoms are described and the use of soil and plant tissue analyses is discussed and instructions for representative sampling are provided. The guidelines provide information about nitrogen, phosphorus, and potassium fertilization. Information on selected micronutrients is included for crops where deficiencies are common.

## **10. Findings:**

The database and the guidelines facilitate and improve access to nutrient management related information considerably. The websites present a comprehensive source of information for growers, certified crop advisers and other interested stakeholders.

The websites are freely available online. The information presented supports efforts by growers and crop advisers to improve nutrient use efficiency in crop production, thus advancing the environmentally safe and agronomically sound use of fertilizing materials.

## **K. COPY OF THE PRODUCT**

The products of this project are websites hosted by CDFA-FREP. The websites are freely available.

The database can be accessed here:

<http://www.cdfa.ca.gov/is/frep/Default.aspx>

The fertilization guidelines can be accessed here:

<http://apps.cdfa.ca.gov/frep/docs/guidelines.html>

**CA.GOV** CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE  
**INSPECTION SERVICES DIVISION**

CDFA Home Inspection Home Programs Apply/Register Laws & Regs Meetings Contact Us

Chem Lab Feed, Fertilizer, L/S Drugs Inspection & Compliance

**20 years OF FREP RESEARCH**

CDFA Home > Inspection Services > FREP Database

### FREP DATABASE

The Fertilizer Research and Education Program (FREP) funds and coordinates research to advance the environmentally safe and agronomically sound use and handling of fertilizer materials. Since 1990, FREP has funded research on many of California's important and environmentally sensitive cropping systems. This database aims to make the wealth of information contained in FREP research projects readily available, easily understandable, and convenient for growers to implement.

Please enter search criteria:

Keyword(s)	<input type="text"/>
Type of Crop	<input type="text" value="View All"/>
County	<input type="text" value="View All"/>
Date Range	<input type="text" value="View All"/>
<input type="button" value="Search"/>	

For more information, please contact FREP staff at 916-900-5022 or [frep@cdfa.ca.gov](mailto:frep@cdfa.ca.gov)

**Figure 1:** Start site of the database allowing users to enter search criteria (online at <http://www.cdfa.ca.gov/is/frep/Default.aspx>).

## STUDY RECORD

# Development of a Nutrient Budget Approach to Fertilizer Management in Almond

Brown, P., Department of Plant Sciences, University of California, Davis

## Project Highlights

- Nitrogen use efficiency can be optimized by adjusting fertilization rate based on realistic, orchard specific yield, accounting for all N inputs and adjusting fertilization in response to spring nutrient status and yield estimates.
- 1000 lb almond kernel removes (in all fruit parts) from the orchard 68 lb N, 8 lb P and 80 lb K.
- Leaf analysis following full leaf out and again in the late summer is an important monitoring strategy.
- Applications to match demand in as many split applications as feasible.
- 80% of N uptake occurs from full leaf out to hull split in almond.
- If trees are healthy and capable of N uptake from soil, up to 20% of N can be applied after fruit maturity or immediately post-harvest.

## Introduction

Environmental legislation is forcing a change in farming practices as a result of many years of excess nitrogen (N) application and loss of N below the root zone and consequent contamination of water resources. One of the main opportunities to optimize nitrogen fertilization is to synchronize applications with plant crop demand and apply N coincident with root uptake. This project has provided the data needed to correctly estimate the right rate and right time of fertilizer application for efficient and environmentally sound practices.

## Methods/Management

A large experiment covering approximately 100 acres was initiated in 2008 in Belridge, Kern county under fan jet and drip irrigations with four rates of N 125, 200, 275 and 350 lb/ac applied with two N fertilizer sources-UAN 32 and CAN 17. The goal of this experiment was to develop phenology and yield based nutrient demand curves that guide the timing and rate of fertilizer application. Individual tree yield, leaf nutrient analysis and whole tree nutrients were estimated.

## Findings

This project has allowed the development of improved N management practices for almond growers. Nutrient budget curves were developed for the major nutrients and data on timing and quantity of N, potassium (K) and other nutrient uptake and removal from orchards was derived. Budget curves quantify the time course of nutrient uptake and total plant demand as determined by tree yield and nutrients required for growth. Yield potential determines fertilizer strategy and there is a large negative impact on overall efficiency that occurs in years or orchards of poor yield in which standardized fertilization strategies are used. Fertilizing accordingly to predicted yields will dramatically enhance nutrient use efficiency. Findings of this research has been adopted by the Almond Board of California as the new standards for nutrient management and are being widely publicized and distributed.

### Crop

Almond

### County

Kern

### Years of Study

2008 - 2013

### FREP Article

[Final Report](#)

[FREP Proceedings 2008: Page 53](#)

[FREP Proceedings 2009: Page 69](#)

[FREP Proceedings 2010: Page 59](#)

[FREP Proceedings 2011: Page 34](#)

[FREP Proceedings 2012: Page 59](#)

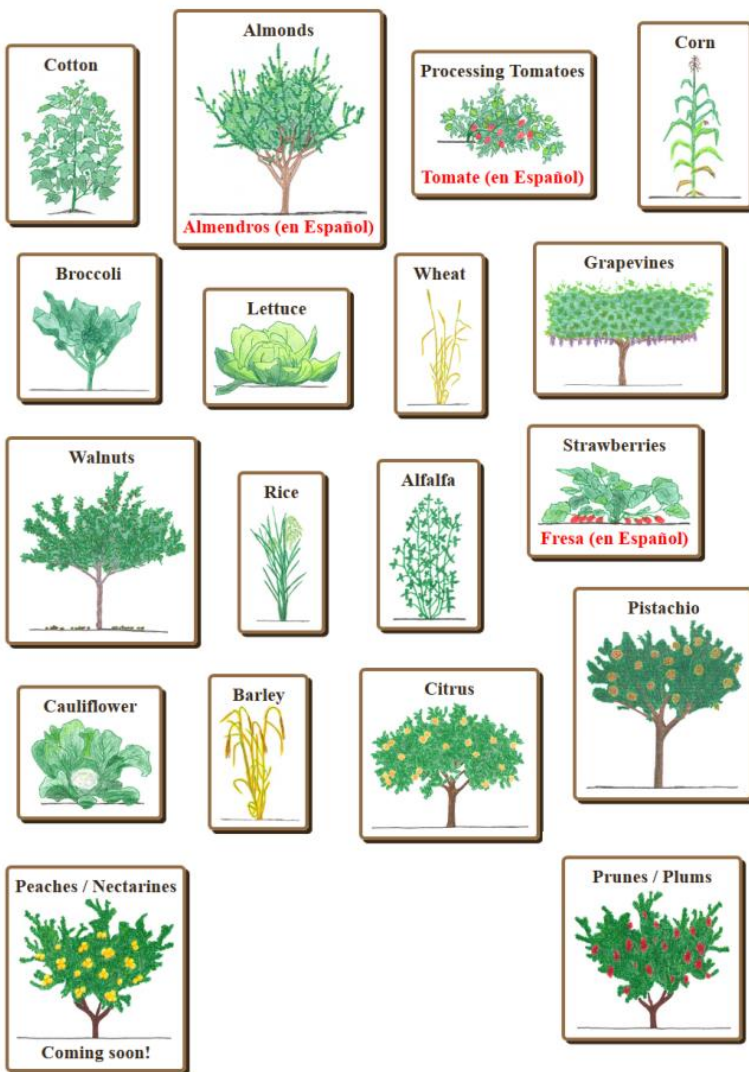
[FREP Proceedings 2013: Page 26](#)

### Fertilization Guidelines

[Almonds](#)

**Figure 2:** Example of an online project summary (online at <http://www.cdffa.ca.gov/is/frep/Default.aspx>).

## Fertilization Guidelines for Major Crops Grown in California



Developed in collaboration by



**UC DAVIS**  
UNIVERSITY OF CALIFORNIA

Department of  
**LAND, AIR AND  
WATER RESOURCES**

### Soil and Plant Tissue Sampling

- [Soil Test Sampling Instructions](#)
- [Sampling for Soil Nitrate Determination](#)
- [Soil Sampling in Orchards](#)
- [Plant Tissue Sampling](#)

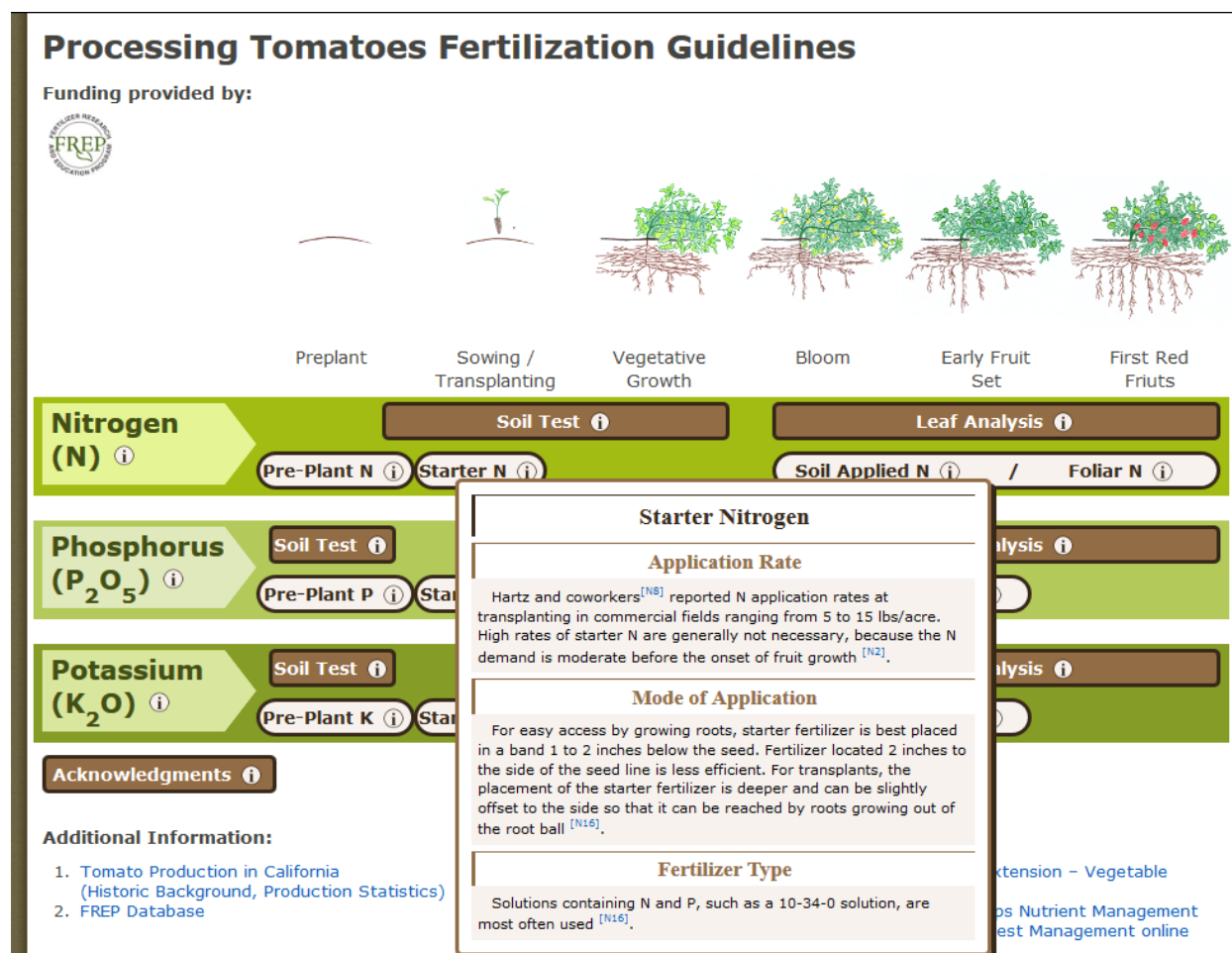
### Additional Resources, Links

- [Organized by Topic](#)
- [Organized by Source](#)

### Nitrogen Partitioning and Seasonal Uptake Curves

**New!** A Discussion about Site-Specific Adjustments

**Figure 3:** Screenshot of the overview page of the fertilization guidelines (accessed on March 17, 2014).



**Figure 4:** Screenshot of the fertilization guidelines for processing tomatoes. By moving the cursor over the different fields, detailed information about the topic is displayed.

## Appendix 1

### Gap Analysis for Nutrient Management in California Crops (September, 2015)

*Daniel Geisseler, Patricia Lazicki and William R. Horwath*

*Department of Land, Air and Water Resources, University of California, Davis*

This gap analysis is based on a literature review conducted to formulate fertilization guidelines for major crops in California. This analysis will mainly focus on nitrogen (N), phosphorus (P) and potassium (K) management of these crops. Though an attempt was made to consider a comprehensive overview of all the existing information, some data will likely never be included. For example, not all results from local trials carried out by farm advisors may have been summarized into reports or various extension materials. In addition, many soil test labs also produce fertilization recommendations based on soil testing, however they often use proprietary algorithms and therefore this information is also not available for this analysis.

#### **Almonds and Pistachios**

Over the last few years, a lot of progress has been made with respect to N fertilization and leaf analyses thanks to the research by Patrick Browns team (funded in part by FREP).

In contrast, P has not been studied widely, mainly because P fertilization has not been found to be beneficial. However, these recommendations are based on older studies in production systems with lower yield potential. In addition, almonds and pistachios are now grown in new regions, where soil properties and climate are different. Therefore, there may be a need to update this information to account for management improvement, soil type and local climates.

Potassium fertilization in almond is necessary and the same issues mentioned for P apply. Almonds and pistachios are now grown on large areas in the San Joaquin Valley. Some soils rich in 2:1 expanding clays such as illite and vermiculite on the east side of the valley are known to fix K. The K fixation issue has mainly been studied for cotton. Whether K fixing soils are also a problem for almonds and pistachios has not received much attention.

Soil sampling to determine residual nitrate in spring is not commonly done in orchards. One issue in perennial crops is that the rooting zone is deeper than in most annual crops. The costs and labor requirements for deep soil cores and the lack of a sampling protocol to account for field variability are limiting factors. Still, it would be interesting to determine how variable residual nitrate is in orchard soils and whether soil sampling for residual nitrate in spring may improve N use efficiency.



## **Appendix 1**

### **Walnuts**

An ongoing project is currently investigating N uptake, N removal, N fertilization management and leaf sampling protocols for walnuts. The results of this project will allow updating the somewhat outdated N fertilization guidelines for walnuts.

As is the case with almonds, P and K recommendations are based on older studies in production systems with lower yield potential. In addition, walnuts are now grown in new regions, where soil properties and climate are different. Therefore, there may be a need to update this information to account for management improvement, soil type and local climates.

### **Citrus**

Most research in citrus nutrient management in California has been done on oranges. Little data is available from lemons, grapefruits or tangerines. A citrus production manual has been published by ANR in 2014. However, a relatively large proportion of research based information available is either from older studies carried out in California or from Florida.

### **Prunes, plums, peaches and nectarines**

Much research has been done on N application to mature California deciduous tree fruits; in particular, whole tree excavation studies from the 1990s and 2000s have given a lot of information on the relative advantages of different fertilizer rates, timings and application methods. For prunes, in which K deficiency is a serious problem, research-based recommendations for K application have also been established. Zinc fertilizer application is also well researched. However, as with almond, almost no recent research has been done on P. For peaches and nectarines there is also very little available research on K, although low-testing K orchards are fairly common.

With the exception of N on young prunes, there is not much available research on the nutrient needs of young stone fruit trees, particularly for P and K. Interesting questions include: safe but sufficient rates and whether it is safe to apply liquid or foliar fertilizers to very young trees.

A sand tank experiment was initiated in the late 1990s with the goal of refining published leaf nutrient critical levels in plums, peaches and nectarines, and to develop critical levels for analysis of dormant shoot samples. The initial published results suggested changes should be made to P and Zn (as well as boron and copper) thresholds. The dormant shoot analysis method also showed some promise. However, more research needs to be done with different varieties and at different locations before these results can be widely used.

As with almond, soil sampling to determine residual nitrate in spring is seldom done in stone fruit orchards.

## **Appendix 1**

### **Grapevines**

At first sight, research results from studies carried out in California appear inadequate and outdated: Most studies on grapevine nutrition have been conducted in the southern San Joaquin Valley with “Thompson Seedless” grapes more than 20 years ago.

However, this impression is somewhat misleading. Yields and nutrient requirements are highest in this region (see: [http://apps.cdffa.ca.gov/frep/docs/grapevine\\_Production\\_CA.pdf](http://apps.cdffa.ca.gov/frep/docs/grapevine_Production_CA.pdf)) and, with the exception of table grapes, yield has not increased much since these studies have been carried out. In addition, in the coastal areas, the focus is on quality and not on yields, effectively limiting the amount of fertilizer applied and reducing the risk of over-fertilization. The need for local fertilization guidelines may also be lower in the coastal areas, as larger vineyards often employ their own staff to optimize production.

### **Lettuce and Broccoli**

A lot of research has been done on these two crops and interesting approaches and tools, e.g. CropManage, have been developed. The main focus may now be on fine-tuning these tools and assure they are adopted by growers.

These approaches and tools could be adapted to other vegetable crops. Therefore, research priorities may shift from lettuce and broccoli to other vegetable crops. However, new approaches and improvements of existing tools may best be done with lettuce and broccoli as model crops, as the database for these two crops is the most extensive.

One field of active research is the contribution of residue N to the following crop. Large amounts of N are returned to the field with residues, especially in the case of broccoli. Good estimates on the amounts of N released and the temporal pattern of N release are crucial to improve N use efficiency in vegetable systems. This issue is currently being addressed in a FREP funded project.

### **Cauliflower**

Much less data is available on cauliflower compared to lettuce and broccoli. However, research is currently being done to expand CropManage to other cool season vegetables, including cauliflower. This will greatly improve growers' ability to manage N in cauliflower.

As mentioned above for broccoli, cauliflower residues also contain large quantities of N which becomes available upon decomposition. Good estimates on the amounts of N released and the temporal pattern of N release are crucial to improve N use efficiency in vegetable systems.

### **Strawberries**

Several research projects have been carried out investigating strawberry nutrient management in California. Research is currently being done to expand CropManage to other crops, including strawberries. This will greatly improve growers' ability to manage N efficiently.

## **Appendix 1**

### **Processing tomatoes**

Research has greatly improved our understanding of nutrient use of tomatoes. However, most of these studies have been done in furrow irrigated tomatoes before the adoption of subsurface micro-irrigation systems within the last decade. Fertigation through the drip tape fundamentally changes the way crops can be irrigated and fertilized. Studies to determine the optimal irrigation and fertigation schedule are needed to further increase water and N use efficiency.

In addition, little is known about the distribution of nutrients and salts in soils under drip-irrigation and how this distribution as well as water infiltration pattern changes over years after the installation of the drip system. Knowledge about the distribution of nutrients will help develop sampling protocols for representative sampling, while knowledge about water infiltration will help to optimize irrigation and fertigation practices and reduce losses of N through nitrate leaching. Furthermore, research is needed to determine how to account for residual nitrate in drip-irrigated tomatoes.

### **Potatoes**

Good potato N management usually depends on locally calibrated variety-specific petiole nitrate thresholds and N uptake estimates, along with intensive soil and tissue testing. However, variety-specific N uptake information of the kind available to growers in the Pacific Northwest is rare for California conditions, especially for the southern potato-growing regions.

Potatoes are heavy K feeders, but because in California they are normally grown on soils with sufficient K and don't often respond to K fertilizer, little research has been done to determine K best management practices in California. Since potatoes deplete soil K over time and more K fertilization is likely to become necessary, more research may be warranted.

Like other rotation crops, a small but growing proportion of potato acreage is under drip irrigation. There is little to no research in California yet on how changing to drip irrigation affects potato fertilizer demand or uptake patterns.

Potatoes have a narrow range in which N is neither deficient nor excessive, and potato quality is also reduced by in-season N fluctuations. They are frequently grown in complex rotations which receive organic matter from various sources. Thus, potato N management would benefit from better ways to estimate the timing and amount of N release from organic materials.

### **Cotton**

The knowledge about cotton fertilization is well established. Most of the research has been done with Acala cotton. Over the last few years, Pima cotton has become the mayor cotton type planted in California. Some research suggests that the nutrient requirement of Pima cotton differ from those of Acala cotton. Anecdotal evidence shows that Pima cotton is now planted at much higher density leading to increases in N use efficiency. However, to our knowledge, not much

## **Appendix 1**

research has been done in California to determine whether different application rates or revised plant density should be used for Pima cotton.

In addition, lower value crops will eventually be irrigated using micro-irrigation systems due to their being in rotation with higher value crops. Little to no information exists for N management under subsurface drip systems in lower value crops and there is a need to not only to reassess fertilizer N management but to study how fertigation in micro-irrigation systems is affects residual fertilizer in different crop rotations.

### **Corn**

Very little information about corn fertilization is available in California. The use of the pre-plant nitrate test, the pre-sidedress nitrate test, as well as leaf or canopy greenness tests have not been tested widely in California. In most states, fertilization recommendations are based on soil nitrate tests with leaf canopy N assessments being used in irrigated corn in the Midwest.

As with cotton, farmers growing corn are experimenting with micro-irrigation since it is a major rotation crop. Anecdotally, corn yields are also increased and suggest that subsurface drip systems increase the yield potential of crops in general. As is the case with cotton and in general for lower value crops, little to no research has been performed to assess fertilizer N requirements in emerging micro-irrigation systems. From long-term research done at UC Davis, corn is a relatively efficient user of fertilizer N yet often leaves considerable residual fertilizer N in soil. The accumulation of residual soil nitrate is likely attributable to the dearth of knowledge regarding fertilizer N needs of corn and corn in complex rotations found in California.

### **Rice**

The knowledge about rice fertilization is well established. Currently, there is a shift towards drill seeding with delayed flooding in order to reduce methane emissions. A change in the flooding pattern also affects N use efficiency and needs to be addressed by future research. Other developments, such as the cessation of rice residue burning and herbicides with limited efficacy in rice production have already been addressed but may require some more work.

### **Wheat**

Ongoing projects are currently investigating optimal N application rates and timing that ensure high yields and protein contents. The results of these studies will allow updating N fertilization guidelines for wheat. Given the fact that wheat is grown across the state in a variety of environments and cropping systems, it will be necessary to verify the results of these studies in different parts of the state and to fine-tune recommendations based on local climate and soil conditions.

Very little recent information about P and K fertilization is available from studies carried out in California.

## **Appendix 1**

### **Barley**

There is little California-specific research on barley fertilization. Most of the available research is from other states and may not be applicable to California's climate and cropping systems. An especially important question for barley is the timing of N application; this also affects appropriate rates.

No critical nutrient levels for tissue analysis have been developed for California barley. Foliar analyses are especially important in malting barleys, which have a fairly narrow range between deficient and excessive N. Research from high-yielding irrigated barley in Arizona suggests that thresholds are lower for malting than for feed barleys; however, no research has been done in California to develop thresholds for malting barleys. Better methods of assessing N status will be complementary to refining timing and rate recommendations.

### **Alfalfa**

Alfalfa obtains N from the atmosphere through a symbiotic relationship with bacteria (Rhizobia) in the root nodules. Therefore, N fertilization is not a big concern. However, large amounts of N are stored in roots and crown and become available to crops following alfalfa. Research is currently being done to determine the need for N fertilizer for wheat following alfalfa. This is an important contribution to tightening the N cycle in crop rotations and needs to be done for crops that differ in their growth habit from wheat as well.

### **General Gaps and Challenges**

1. Increased yield, new varieties, new management practices (e.g. drip irrigation) and the expansion of crops, particularly specialty crops, into areas (and on soil types) where they were not grown in the past will make it necessary to reevaluate current nutrient recommendations.
2. A better understanding of systems nutrient use efficiency is needed. Little research has been done on how the previous crop or cover crops affect N availability to the current crop, including the effect on residual nitrate and N mineralization during the cropping season. Information is needed to design optimal crop rotations and to optimize fertilizer applications for crops in rotation.
3. Large gaps also exist in our understanding of N availability from soil organic matter in different soils, as well as from animal manure and lagoon water and how they may be combined with mineral fertilizers to maximize N use efficiency. In this context, N availability not only refers to the quantity of N, but also to the time N becomes available.
4. Climate change will affect soil processes and microclimates likely altering nutrient cycles. Research is needed to determine the magnitude of change and to reevaluate nutrient requirements.
5. More information on fertilizer types, rates and application methods are required to reduce N<sub>2</sub>O emissions across all crops.

## Appendix 1

6. Recent studies have investigated the K fixation potential of different soils in the San Joaquin Valley. However, little is known about K fixation in other parts of the state. Even less information is available about P fixation and availability in different soils in California.
7. Information on the economics of fertilizer use such as optimum N rate is needed to gauge optimum yields rather than maximum production.
8. New practices and user-friendly tools have been developed to improve nutrient and water use efficiency. However, the challenge is to ensure they are adopted by growers. Economic studies and studies about labor requirements for implementing specific practices may help designing optimal fertilization strategies that are likely to be adopted by growers. Surveys about whether growers adapt certain approaches and tools and when not what are the reasons, may help improve the application of these tools.
9. Where growers get information is critical to the outcome of nutrient management. Many growers obtain their nutrient management recommendations from certified crop advisors and other industry sources. This is a conflict of interest where fertilizer distributors both sell and prescribe fertilizer use to growers. Efforts to provide growers with independent nutrient management information in a user-friendly way need to be continued.
10. The development of “apps” for smartphones and tablets that utilize information on the websites and other information sources described in this report would likely increase the value of the products presented in this report and provide for consolidated information about nutrient management in California to all stakeholders.